

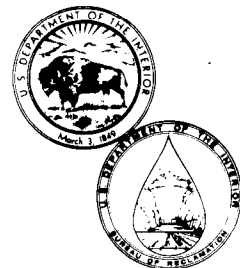
REC-ERC-81-12

DEVELOPMENT OF AN AUTOMATED PLUGGING FACTOR MONITOR

December 1981

Engineering and Research Center

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**DEVELOPMENT OF AN
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by

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December 1981

Applied Sciences Branch
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Denver, Colorado



UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

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This study program was supported by USBR-LCR (Bureau of Reclamation - Lower Colorado Region) from YDP (Yuma Desalting Plant) pretreatment development funds. Charles Goodner, Resident Engineer, YDTF (Yuma Desalting Test Facility), directed the operating evaluation of plugging factor testers and prototype assemblies. Design modifications and fabrications were conducted at the Engineering and Research Center, Denver by the following Division of Research personnel: Roy Eisenhower of the Applied Sciences Branch served as project engineer on the design and construction of the mechanical units. An electronic console was developed by Cary A. Loeser and Larry R. Brandt of the Division of Research, Power and Instrumentation Branch. The second-phase modifications of the console were done by Steven C. Stitt, Gilbert Brown, and Jack Hodgson of the Computers and Automation Section. An unusually heavy responsibility of effort and skill, which enabled the program to continue, was placed on Donald Matti, and Gary Boothe of the Laboratory Shops.

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

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INTRODUCTION

The quality of feed water delivered to a membrane-type desalting plant largely determines membrane performance and longevity. Feed water quality can be monitored by a method called the PF (plugging factor) which is an indication of the quantity of particulate matter present in the water flowing to the desalting membranes. In the early 1970's, a manual PF test was developed for the Government by Millipore¹ and du Pont.² Since then, this test has been generally accepted throughout the desalting industry as a criterion for determining the fouling tendency of membrane feed water. In an operating plant, or in a large test facility, such as the YDTF (Yuma Desalting Test Facility), Yuma, Arizona, or in the Department of the Interior, OWRT (Office of Water Research and Technology) test facilities, each manual determination of PF requires a considerable amount of operator time. To reduce this workload, OWRT contracted with private industry to develop an automatic CPM (continuous plugging factor monitor). While the feasibility of automatic plugging factor measurement was determined with these units, they lacked the needed reliability, repeatability, and accuracy.

In February 1979 a research project was implemented at the Bureau of Reclamation, Engineering and Research Center, Denver, Colorado to design and fabricate a totally automated PFM (plugging factor monitor) with the required reliability, repeatability, and accuracy. This new prototype was to include an electronic controller unit, a mechanical water sample selector unit, and a mechanical test unit. The operation of the prototype PFM was evaluated during 1980 at the YDTF. As a result, several additional electronic and mechanical improvements were made. The two mechanical units are described in this report; however, the electronic controller unit is described in another report [1].³

CONCLUSIONS

A reliable automatic device for accurately monitoring the PF has now been designed, built, and tested. The unit is totally automatic and does not require an operator during the testing cycles. Very accurate PF records can be obtained every 20 minutes, 24 hours per day. This PFM unit is recommended for use at the YDTF, the future YDP (Yuma Desalting Plant), and for other Government or commercial membrane-type desalting facilities. Design specifications for the SPSBP (sample point selector booster pump) mechanical unit, the PFM-T (tester) mechanical unit, and the PFM-EC (electronic controller) console have been prepared by the Government and are available to all Government agencies or private industry.

DISCUSSION

The PF (plugging factor) is defined as follows. It is a measure of the rate at which the pores in a Millipore 0.45 μ m pore diameter, cellulose-acetate filter, become plugged with particulate matter while water is being filtered through it at a constant pressure (207 kPa). In this PF test, the time is recorded for a 500 mL of water sample to flow through a 1320 mm² filter area membrane filter. This time is called (t_1)⁴. Sample water is allowed to flow through the filter for 15 minutes, and then a second 500 mL is collected, and the time, called (t_2), is again recorded. Since the filtrate volume is fixed during the first and second flow rate measurements, only the times t_1 and t_2 required to collect the first and second volumes, need to be known to calculate the PF.⁵

The percent PF is calculated as follows:

$$\% \text{ PF} = \left(1 - \frac{t_1}{t_2} \right) \times 100$$

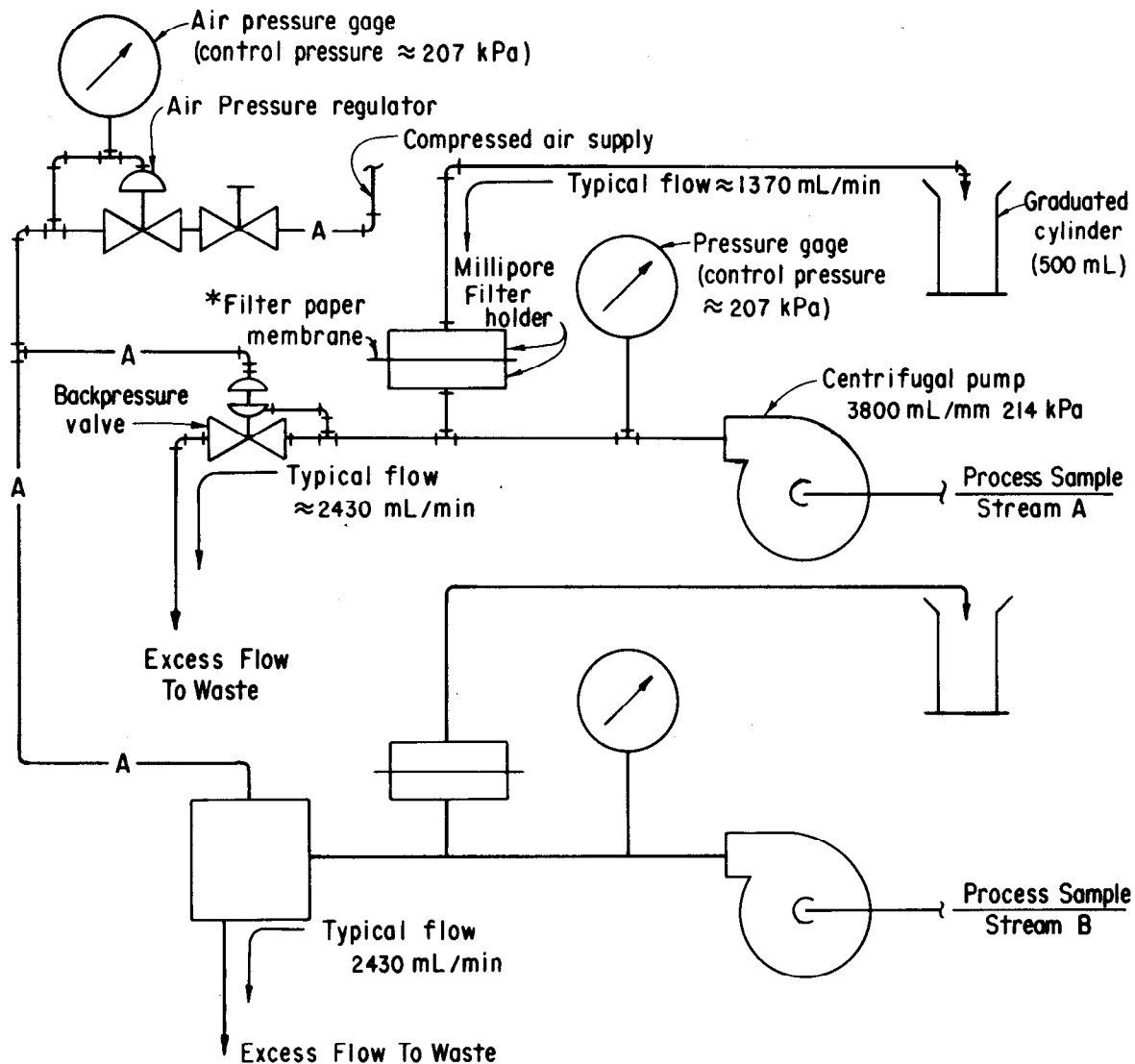
¹Millipore Corporation, Wiggins Avenue, Bedford, MA 01730

²E.I. du Pont de Nemours & Company, Inc., Glasgow Site, Wilmington, DE 19898

³Numbers in brackets refer to entries in the bibliography.

⁴All time is recorded to an accuracy of one-tenth of one second.

⁵A theoretical discussion of the parameters contributing to the PF is given in appendix A.



* Millipore (membrane) filter type HAWP 0.45 μm , 47 mm dia, 1320 mm^2 filter area

Figure 1.—Schematic diagram of the YDTF manual plugging factor apparatus.

The YDTF Manual Plugging Factor Apparatus

A manually-operated^a PF tester (fig. 1) that samples flow from various places in the pretreatment process was developed at YDTF. The sample for this test is pumped directly from the process stream through the 0.45 μm pore diameter filter, minimizing the time required to prepare the equipment for each test. The procedure still requires that t_1 and t_2 be determined by timing the

^aOperating instructions for the YDTF apparatus are attached as appendix B.

collection of a 500-mL water sample through a 1320 mm^2 filter area, into a graduated cylinder, and that the PF be calculated manually. This procedure requires considerable attention and skill because the operator must obtain exactly 500 mL of filtrate and must record the exact times.

Continuous Plugging Factor Monitor

The OWRT contracted with private industry (du Pont) to develop an automatic CPFM. Two of the monitors (fig. 2) were designed and built under the contract for the Bureau. The units

were designed to filter 131 mL through a 345 mm² filter area of 0.45 μ m pore diameter membrane. The performance of each monitor was evaluated [2] for 4 months at YDTF where they were found to have a number of limitations:

- The precision was poor, particularly when the PF's were lower than 50 percent. There was considerable scatter (fig. 3) when data obtained from the YDTF manual plugging factor apparatus were compared with those obtained with the CPFM system. An error analysis indicated systematic and random measurement errors in both the monitor and the manual method.
- The filter tape broke frequently, resulting in poor reliability of the system.
- No automatic calculation or recording of the PF results was provided, nor did the monitor have process control or computer interfacing capability.

It was obvious that the manual methods of measuring the PF were labor intensive and that accuracies depended greatly on the skill of the operator. It was also apparent that these first automated units which were manufactured for the Government lacked reliability and accuracy, and still required the operator to manually calculate the PF.

Automatic PFM (USBR Design)

The Resident Engineer (YDTF) requested that an instrument be developed at the Bureau, Engineering and Research Center, Denver, Colorado that would automatically and accurately determine PF's sequentially for up to six different pretreatment process water samples. A PFM was developed and constructed, as requested, which included the PFM-EC (PFM-electronic controller) console, the SPSBP (sample point selector booster pump) and the PFM-T (PFM-tester).

The PFM-EC. — The electronic controller console (fig. 4) designed, fabricated, and evaluated by the Bureau, is described [1] elsewhere.

The PFM-EC has the following capabilities:

1. Automatic control of sequential operations are provided for the six-position SPSBP and the PFM-T unit.

2. The functional problem audible alarm operates with each indicator light for five separate malfunction indications. Each must be manually reset by pressing the alarm reset button. For all alarms except filter membrane paper breakage, the unit will proceed to the next sample stream and continue to operate.

- **PLUG FACTORS ALARM** This indicates that the PF is higher than the preset limit, as adjusted by the preset PLUG FACTOR ALARM LIMIT (%) control on panel.
- **T₁ ALARM** The time t_1 has exceeded the preset limit as adjusted by the TIME T₁ ALARM LIMIT (SECONDS) control.
- **T₂ ALARM** The time t_2 has exceeded the preset limit as adjusted by the TIME T₂ ALARM LIMIT (SECONDS) control.
- **FILTER PAPER ALARM** The paper supply reel has stopped due to filter paper breakage or other paper feed malfunction.
- **PRESSURE ALARM** An unusually long time has occurred from start of sample flow until the measuring collector tank elevation touches the bottom electrode, which would indicate a water pressure problem. This is adjusted by the CYCLE TIME (MINUTES) control.

3. One, all, or any combination of six water sampling locations may be manually selected, and placed on active or inactive sampling mode.

4. The PF is calculated automatically and presented on the digital display for any or all of the six activated water sampling locations. Each display is maintained until the unit cycles through all of the other selected positions and completes another test on that position.

5. A digital display clock shows the current time with a display of the Julian day, hour, and minute.

6. Cycle length of time set point may be changed to some time other than the normal 15-minute test time. It is convenient, when bench-testing the unit, to reduce or eliminate the 15-minute flow portion of the test.

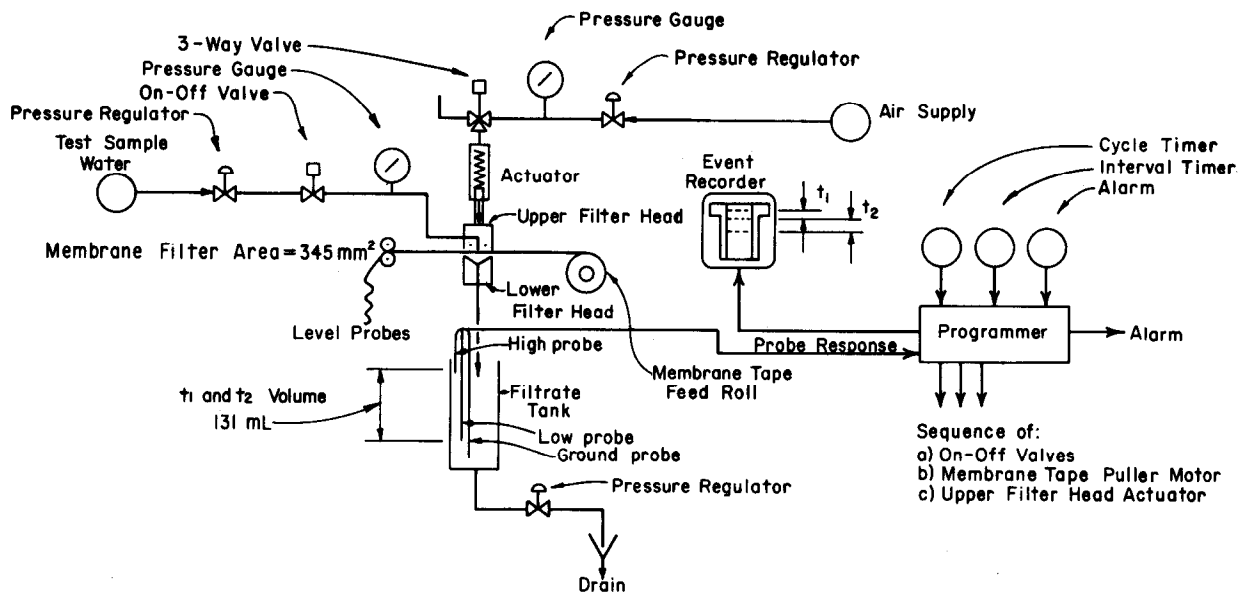


Figure 2. — Schematic diagram of the private industry constructed continuous plugging factor monitor.

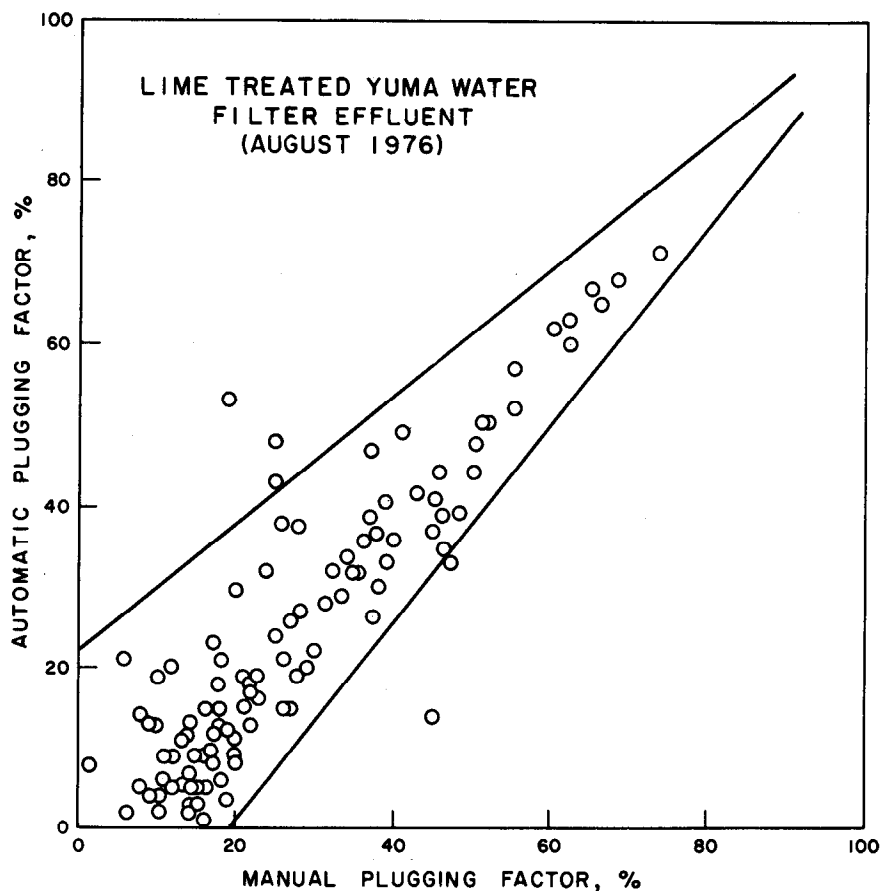


Figure 3. — Scatter diagram of plugging factors for YDTF manual plugging factor apparatus versus the CPM equipment.

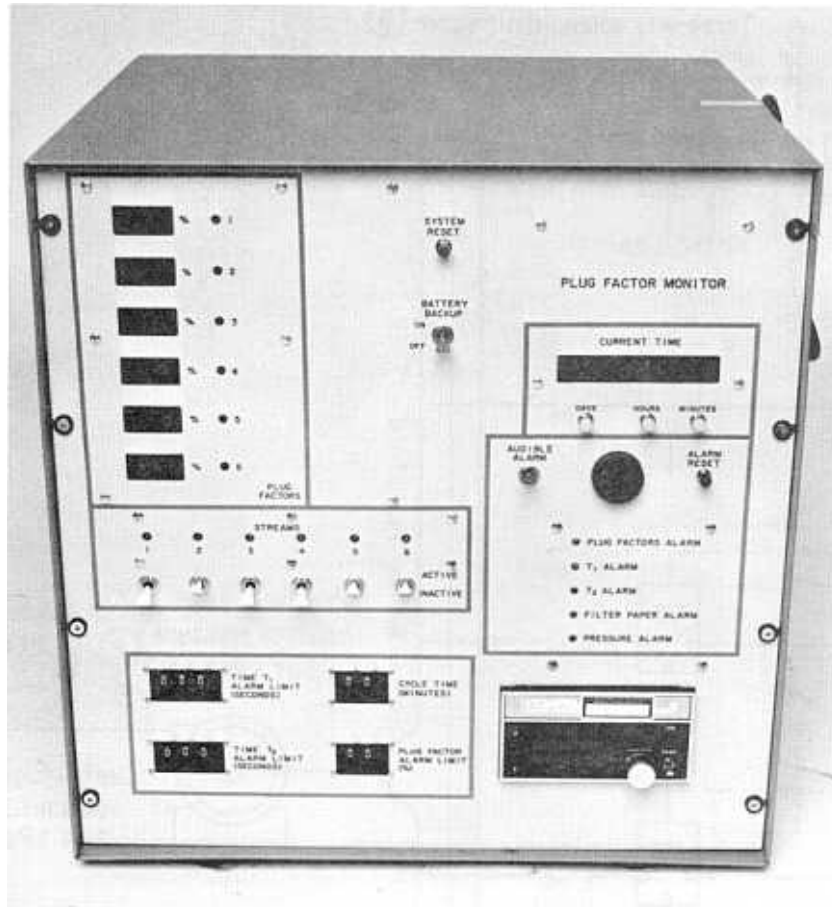


Figure 4. — The PFM-EC electronic controller console. Photo P801-D-79702

7. The unit can produce a tape printout of the date, time, location sampled, t_1 , t_2 , PF, and alarms triggered, for each flow sampled.

8. A 4 to 20 mA current interface is provided for external monitoring of the six test stream locations.

The SPSBP. — The sample point selector booster pump unit (figs. 5, 6) is controlled by the PFM-EC as follows:

- The unit may be connected to as many as six water sample sources where it is desired to run a PF test.
- When a three-way diverter valve is not activated, the sample water continually flows to the drain. Each valve is compressed-air

operated, which in turn is controlled by an electrically activated three-way solenoid air valve.

- When a three-way diverter valve is activated, water is diverted and fed into the water manifold and into the centrifugal pump.
- The water to be sampled flows into the two-stage centrifugal pump which increases the pressure from a plant source pressure to PFM-T unit pressure which is 207 kPa.

The PFM-T. — The plugging factor monitor tester (figs. 7, 8) is operated as follows:

1. The water sample flows into the tester at 207 kPa pressure from the SPSBP unit.

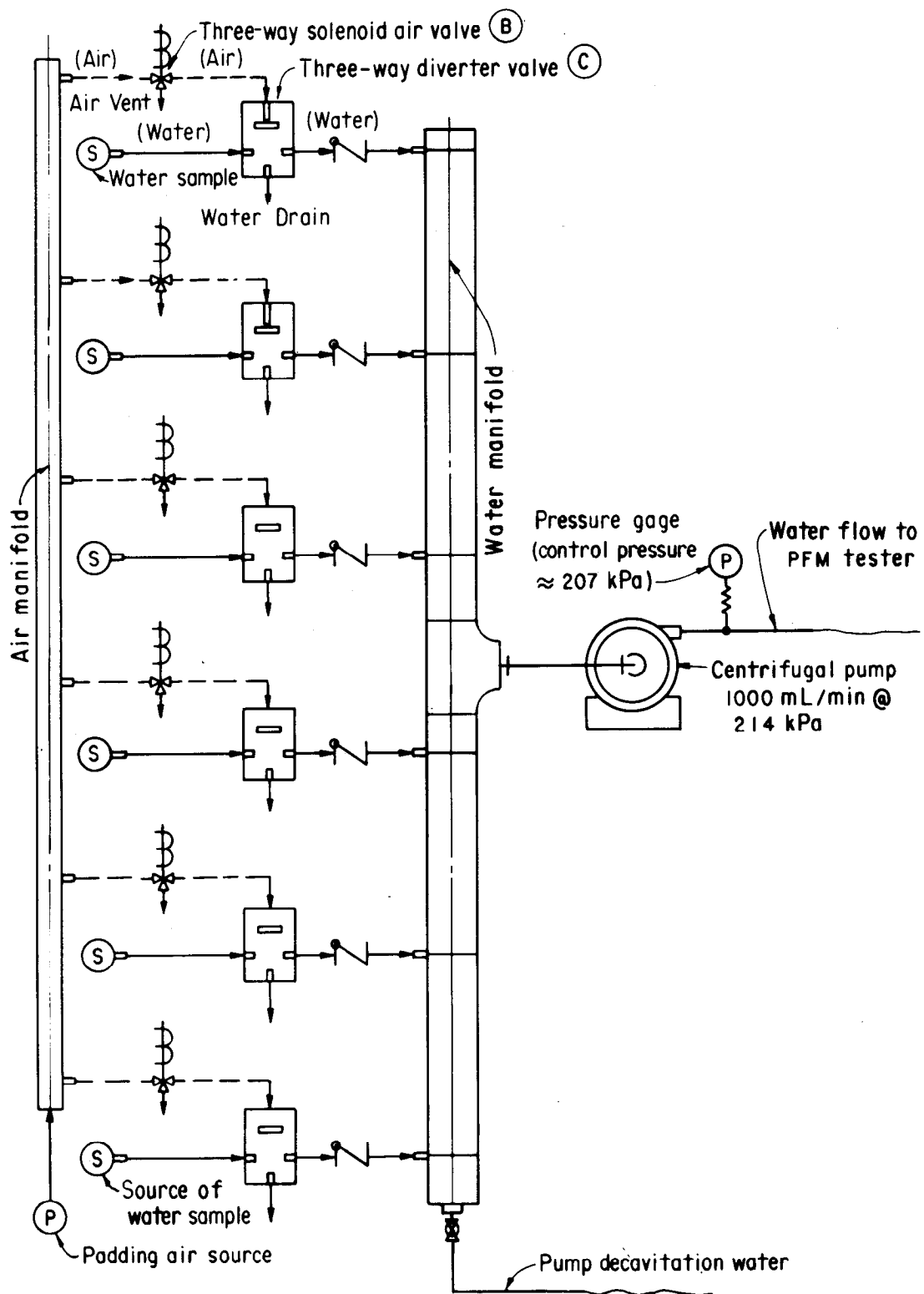


Figure 5. — Schematic diagram of the sample point selector booster pump.

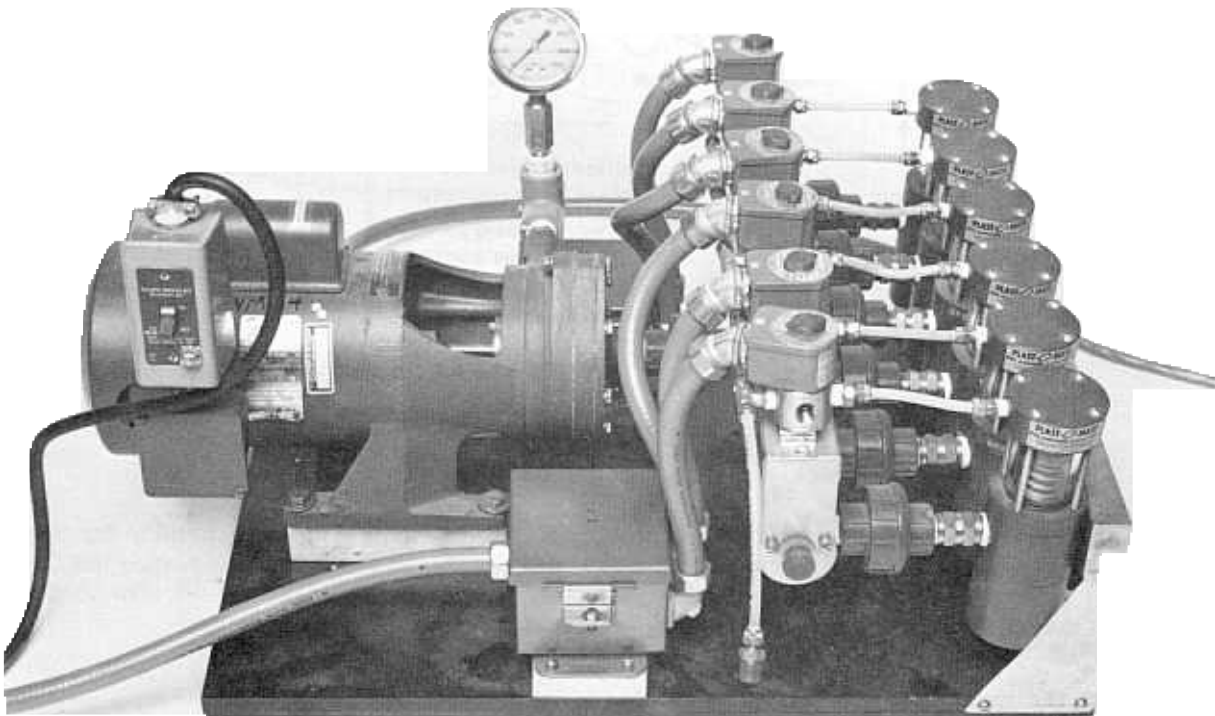
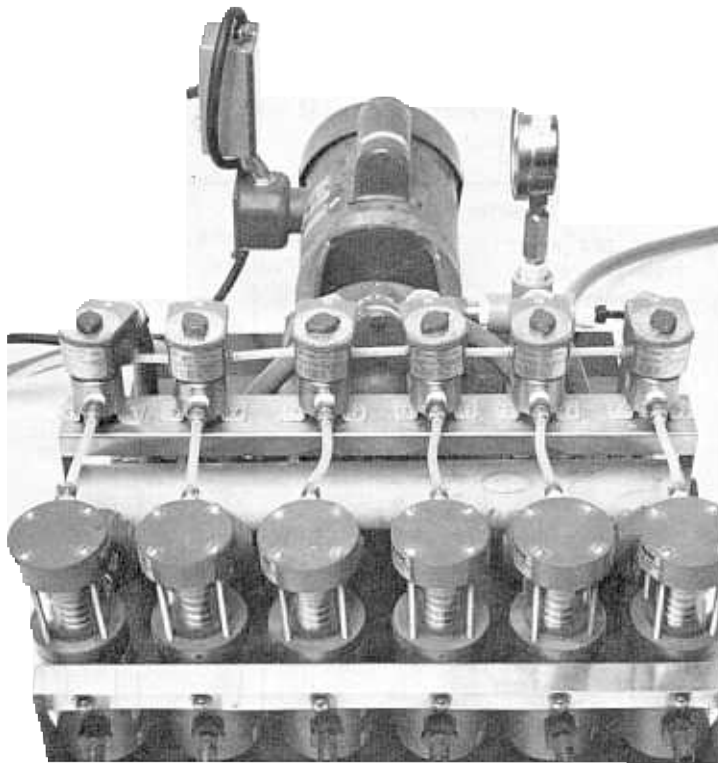


Figure 6. — The sample point selector booster pump unit. Photos P801-D-79703 and P801-D-79704

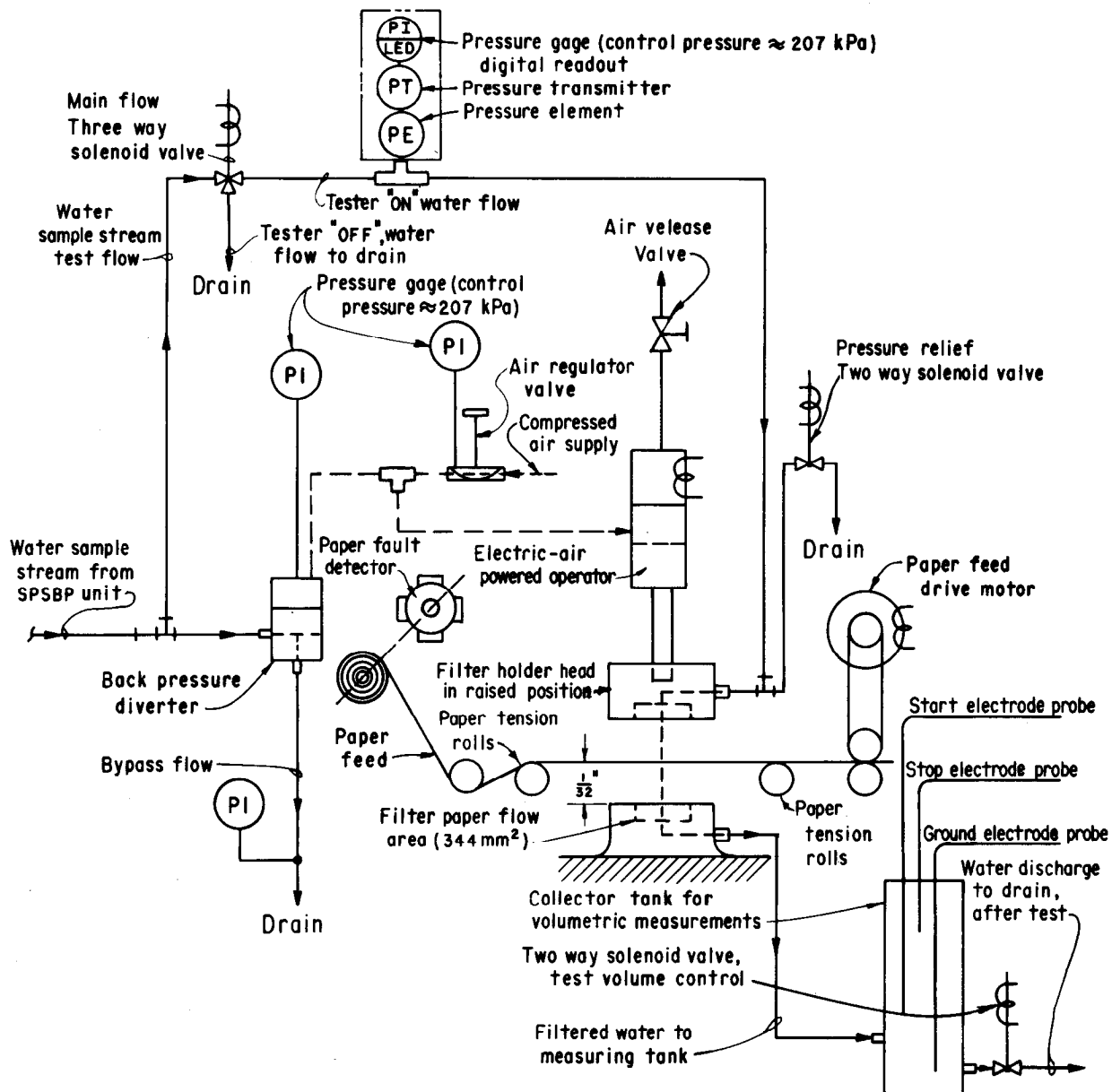


Figure 7. — Schematic diagram of the plugging factor monitor tester.

2. Sample water pressure is held constant by the air-pressure-controlled back pressure diverter which relieves overpressure by diverting part of the water flow to the drain.

3. When the main flow three-way solenoid valve is deenergized, all of the flow is diverted to the drain, and the tester is in "test-off" condition.

4. At the beginning of each test, the paper drive motor is energized to advance the 0.45 μm membrane filter about 40 mm through the open filter heads.

5. The electric-and-air operated piston is energized to compress the filter paper between the filter holder head and base.

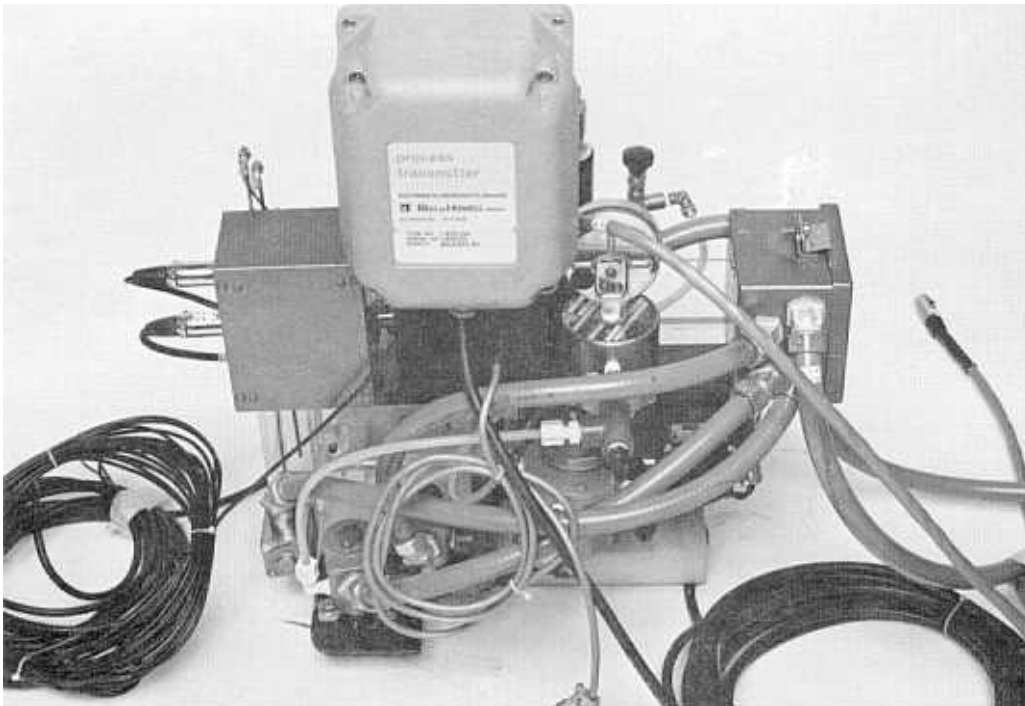
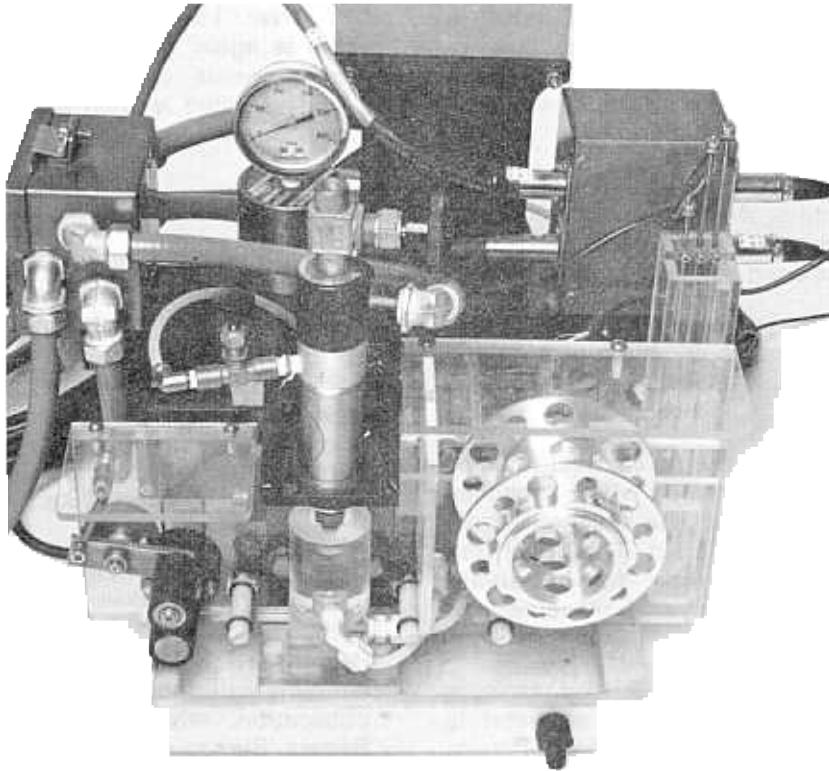


Figure 8. — The plugging factor monitor tester. Photos P801-D-79705 and P801-D-79706

6. When the three-way solenoid valve is energized ("test-on" condition) the flow to the drain is shut off and all flow is through the back pressure diverter to the filter holder head.

7. Sample water flows through the filter paper and enters the measuring collector tank and flows to the drain through the normally open test drain solenoid control valve.

8. The test starts when the test drain solenoid control valve is energized, which closes the drain, and allows the tank to start filling.

9. Time starts when the liquid level reaches the start electrode and stops when it reaches the stop electrode and the solenoid drain valve is deenergized to open. The upper and lower electrodes are preset for measuring 131 mL of water. The first such measurement is labeled(t_1).

10. With the valve opened, the tank is drained and the sample stream of water is allowed to flow for 15 minutes into the drain.

11. After 15 minutes the solenoid drain valve is again closed, and again volumetric measurements are recorded to determine (t_2). The valve is then deenergized and the test is over.

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- [1] Stitt, S.C., C.A. Loeser, J. M. Hodgson, and G. Brown, "A Microprocessor-Based Controller for the Plugging Factor Monitor," Report No. REC-ERC-81-4, Bureau of Reclamation, Denver, Colo., May 1981.
- [2] "Automatic Plugging Factor Monitor Test Results, Yuma Desalting Test Facility," Burns & Roe Industrial Services Corporation, Paramus, N.J., February 1977. [Appendix A contains information from a portion of this publication, which was written by Eric A. Rogers, Bureau engineer.]

APPENDIX A

A THEORETICAL DISCUSSION OF THE PLUGGING FACTOR AS A MEASUREMENT OF RO FEED WATER QUALITY

The plugging factor test is a measurement of the percent decrease of flow rate through a 0.45 μm filter membrane with a constant pressure differential of 207 kPa (gage) after 15 minutes. It is theorized that the decreased flow is due entirely to particles plugging some of the pores in the filter membrane. If so, the resulting percentage of flow reduction is related to the percent of plugged pores. If the total number of pores in a new filter pad and the total volume of flow during the test are known, the number of plugging particles per unit volume can be calculated.

It is assumed that the plugging particles consist of only a small segment of the size range of all the particles in water. Particles smaller than 0.45 μm would pass through the filter pad; larger particles would be held at the surface of the filter pad, allowing water to flow around them, and thus would have little effect on the flow rate through the membrane. We assumed that for each plugged pore, one particle within this narrow size range had been trapped, and was completely plugging the pore.

Initially an open pore has a constant flow, dependent upon a constant differential pressure across that pore. The flow through a pore is considered individually and independent of all the others. The total flow is then the sum of the flows through the total number of pores.

Therefore,

$$F = nk \quad (1)$$

Where F equals the total flow and n equals the total number of open pores, at the time t_1 , and k equals the flow rate through each individual pore. At any time during the test, the number of pores which remain open can be expressed as

$$n = n_o - ab \quad (2)$$

where n_o equals the number of open pores initially

a is the number of particles capable of plugging pores per unit volume of liquid

b is the total volume of liquid which has passed through the membrane filter since the start of the test.

Therefore,

$$F = (n_o - ab)k \quad (3)$$

However, from b and F as defined, at any particular instant

$$\frac{db}{dt} = F \quad (4)$$

And rewritten as a nonhomogeneous first-order differential equation, equals:

$$\frac{db}{dt} + abk = n_o k \quad (5)$$

Solving equation (5) with the boundary condition that must be satisfied at $t = 0$ (also $b = 0$), the number of open pores (n_o) must be maximum, gives:

$$b = \frac{n_o}{a} + ce^{-akt} \quad (6)$$

and at $t = 0$, $b = 0$, and

$$c = \frac{-n_o}{a} \quad (7)$$

Substituting equations (6) and (7) into (3) gives

$$F = n_o k e^{-akt} \quad (8)$$

Each pore acts as an independent orifice and follows Bernoulli's equation, therefore the flow rate (k) equals:

$$k = C \sqrt{\Delta P} \quad (9)$$

where: C = a constant of proportionality,

ΔP = the pressure drop (207 kPa) across the membrane filter.

Equation (8) in terms of pressure drop then becomes

$$F = n_o C \sqrt{\Delta P} e^{-atC \sqrt{\Delta P}} \quad (10)$$

APPENDIX B

OPERATING INSTRUCTIONS FOR THE YDTF MANUAL PLUGGING FACTOR APPARATUS

1. Install a new Millipore filter.
2. Adjust the pressure regulator to a downstream air pressure of 207 kPa.
3. Start pump.
4. As soon as the pressure gage indicates 207 kPa (gage) simultaneously start a stopwatch and begin collecting water in a 500-mL graduated cylinder.
5. When 500 mL of water collects, stop the watch and record the time on the stopwatch as t_1 . Start the 15-minute flow of water to the drain.
6. Continue the flow of water to the drain for 15 minutes.
7. Repeat test, step 4.
8. When 500 mL of water has been collected the second time, record the time on the stopwatch as t_2 .
9. Calculate the PF (plugging factor) according to the following equation:
$$\% \text{ PF} = \left(1 - \frac{t_1}{t_2} \right) \times 100$$
10. After each test, remove the Millipore filter and clean the filter holder.

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